

# SIGNAL PROCESSING ALGORITHM FOR OFDM CHANNEL WITH IMPULSE NOISE

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**ABSTRACT:** Orthogonal frequency division multiplexing (OFDM) has received a considerable attention for realisation of high-speed communication systems. Digital data is transmitted on  $N$  subchannels simultaneously, and the frequency responses of the subchannels are overlapping and orthogonal. To avoid interference between adjacent channels, the guard interval in frequency domain is used. Impulse noise is bursty, high amplitude, low probability noise, taking the form of the time domain impulse. Such impulses of very short duration contain spectral components on all subchannels, and thus impact the decision of symbols transmitted on all subcarriers.

The receiver detects the presence and the position of the impulse within the OFDM symbol by combining the power calculation in time and frequency domain. Samples corrupted by impulse noise are reconstructed by using redundancy of the guard band in the frequency domain. Simulation results for moderate Signal-to-Noise-Ratios are reported.

## 1. INTRODUCTION

OFDM modulation scheme is used in many high speed communication systems, such as Asymmetric Digital Subscriber Line (ADSL), Digital Audio Broadcasting (DAB), high speed access to Internet via power lines, etc. The research in this paper has been performed for power line communications, but the results obtained may be used in other multitone communication systems as well.

Low voltage electrical power distribution network, is a rather hostile communication channel. To overcome frequency selective attenuation, a relatively simple equaliser can be used. The equaliser calculates only one complex coefficient per subchannel, and because of slowly varying nature of the channel transfer function, the decision feedback equaliser offers satisfactory performance. The influence of strong narrow-band interference can be reduced by the usage of bit loading algorithm, to avoid channels with high level of interference [1].

However, the impulse noise, which is the consequence of the switching processes on the power distribution network, can significantly influence the performance of the OFDM communication system. There are many reasons for this statement, among which are:

- Impulses usually have very high amplitude, and thus high energy, which can be much greater than the energy of the useful signal. Because of the high peak-to-average ratio of the OFDM symbol, limiter will not provide satisfactory performance.
- Shapes of the impulses are not known and they vary significantly.
- The time of the arrival of an impulse is unpredictable and it is complicated to model its probability density function. The model and the shape of an impulse may vary from location to location.

The problem of impulse noise was, till now, solved exclusively by channel coding. The exception is the signal processing algorithm presented in [2]. However, the algorithm proposed in [2] has to recognise the shape of an impulse, and may introduce significant error if the impulse shape is not correctly estimated.

The algorithm proposed in this paper uses redundancy in the frequency domain to cancel the impulse noise in time domain.

On the edges of the frequency band employed by the communication system, the amplitude of a few subcarriers is set to zero, to avoid interference between neighbouring frequency bands. The number of such subchannels is a design parameter of the system.

Some other restrictions on the signal constellation in complex plane may also be used to enhance the system performance or to increase the length of the allowed impulse length. If, for example,  $M$ -ary phase shift keying (MPSK) is used as a modulation technique on subcarriers, the additional restriction is that power on all subcarriers is equal and known (up to a constant determined by the equaliser).

The receiver algorithm presented in this paper detects the position of the impulse noise within the OFDM symbol, and recalculates corrupted time domain samples by using the known signal power in frequency guard band.

## 2. OFDM SYSTEM

The block diagram of an OFDM modulator is depicted in Fig. 1.  $N$  differentially encoded complex valued digital symbols  $u_n$ ,  $n = 0, \dots, N - 1$ , (often called frequency domain symbols) are used as an input to the IFFT block.

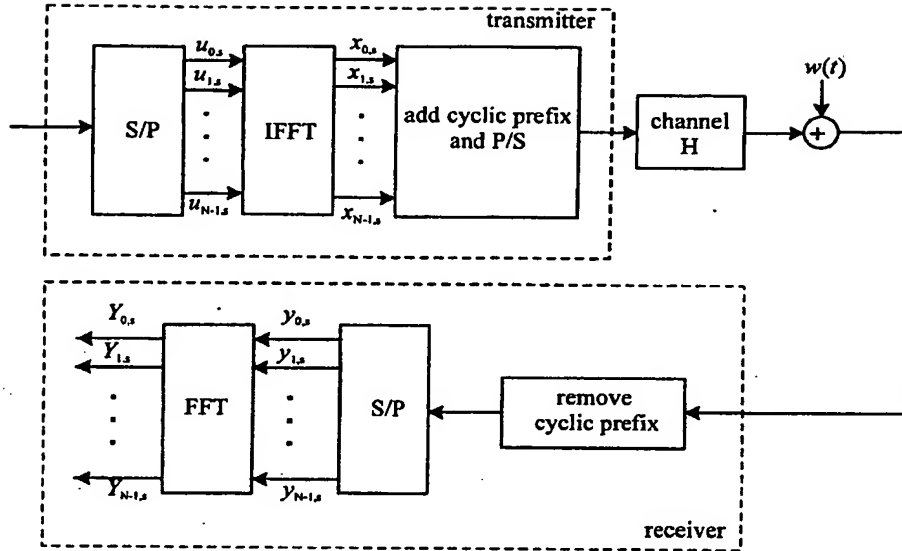


Fig. 1: Block diagram of the OFDM system

The FFT block produces a corresponding block of samples  $x_k$  (called time domain symbols) through inverse discrete Fourier transform [3]:

$$x_k = \frac{1}{N} \sum_{n=0}^{N-1} u_n \exp\left(\frac{j2\pi nk}{N}\right) \quad k=0, \dots, N-1 \quad (1)$$

If the guard band of length  $L$  in frequency domain is used, the  $L$  symbols on the edge are set to zero:

$$a_0 = a_1 = \dots = a_{L-1} = 0 \quad (2)$$

Under the assumption of ideal frame recovery and an ideal channel, the received signal samples are:

$$y_k = x_k + w_k + w_{imp\_k} \quad (3)$$

where  $w_k$  represents Gaussian noise with independent real and imaginary components, and  $w_{imp\_k}$  samples of the impulse noise.

At the receiver, the output from the FFT block is:

$$Y_m = \sum_{k=0}^{N-1} y_k \exp\left(-\frac{j2\pi mk}{N}\right) \quad m=0, \dots, N-1 \quad (4)$$

Due to properties of IDFT-DFT transform pair, we finally have:

$$Y_m = u_m + \mu_m + \mu_{imp\_m} \quad m=0, \dots, N-1 \quad (5)$$

where  $\mu_m$  has the same statistical properties as  $w_k$ , and  $\mu_{imp\_m}$  represents the influence of the impulse noise [4], [5]. Discrete Fourier transform of the impulse has all spectral components, and thus the additive impulse corrupts all subchannels.

### 3. THE DETECTION OF AN IMPULSE

To be able to correct samples corrupted by impulse noise, the receiver has to determine which samples are corrupted, i.e. to determine if there was an impulse noise in current symbol, and, if yes, to calculate its position. To detect impulse noise and determine its position, amplitude, power, auto-correlation function or spectrum of the received signal, or the combination of the above, can be analysed. To detect the presence of the impulse, we will use the combination of the spectrum analysis method and power calculation method. Let us mark the output of the impulse detector in the symbol  $q$  as  $CSI(q)$  ( $CSI$  stands for channel state information).

We will say that the impulse is present when one of the following events occur:

1. The power of the received symbol is at least  $A$  times higher than maximal signal power received when no impulse was detected. For M-ary phase shift keying, the symbol power is independent of the digital information and is equal to 1 (in normalised system). The constant  $A$  is always larger than 1, and its value depends on the length and the power of the impulse that we want to detect. However, it should not be too small to produce the false alarm.
2. If the power of the part of the spectrum corresponding to the guard frequency band is at least  $B$  times ( $B < 1$ ) larger than the power on all spectral components. The value of  $B$  depends on

the relative width of the guard band to the width of the channel and on the power of the impulse. These two conditions can be described with the following equation:

$$CSI(q) = \begin{cases} 1 & \text{if } P(q) > A \cdot P_{\max} \\ 1 & \text{if } \sum_{m=0}^{L-1} |Y_m|^2 > B \cdot \sum_{m=0}^{N-1} |Y_m|^2 \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where  $P(q)$  represents the power of the received symbol and is equal to

$$P(q) = \frac{1}{N} \sum_{k=0}^{N-1} y_{k,q}^2 \quad (7)$$

To determine the impulse position within the symbol, the power calculation on sliding window in the time domain will be used. We will say that the impulse of length  $L_{imp}$  begins on the time sample with index  $l_b$  if the power on the following  $L_{imp}$  samples is larger than the same power for any other  $l$ , i.e.:

$$l_b = \arg \max_l \left[ \sum_{k=l}^{l+L_{imp}-1} y_k^2 \right] \quad (8)$$

#### 4. THE RESTAURATION OF SAMPLES CORRUPTED BY IMPULSE NOISE

The process of restoration of samples corrupted by impulse noise will be explained on an example. We will analyse the case of OFDM system with 16 subcarriers, 2 of them belonging to the frequency guard band, i.e.  $N=2 \cdot 16=32$  and  $L=2$ . Each of the other 14 subchannels carries 2 information bits, and the modulation method on the subcarriers is QPSK. To ensure a real valued sequence at the output of the IDFT block, a Hermitian symmetry condition is imposed, i.e. the frequency domain symbols in modulator are set to:

$$\tilde{u}_k = \begin{cases} u_k & 1 \leq k \leq N/2-1 \\ u_{N-k}^* & N/2+1 \leq k \leq N-1 \\ \text{Re}(u_0) & k=0 \\ \text{Im}(u_0) & k=N/2 \end{cases} \quad (9)$$

In Fig. 2, time and frequency domain symbol in various stages of signal processing in receiver is shown. Frequency and time domain symbol in the transmitter are depicted in Fig. 2 (a) and (b) respectively.

In the received signal, the position of the impulse is determined by the method presented in the previous chapter, and the corresponding samples are set to zero:

$$r_{kz} = \begin{cases} 0 & \text{if } y_k \text{ corrupted} \\ y_k & \text{otherwise} \end{cases} \quad (10)$$

On the signal  $r_{kz}$ , the DFT is performed, and its spectrum is:

$$R_z(k) = DFT(r_{kz}) \quad (11)$$

The spectrum  $R_z$  contains spectral components on the frequencies in the guard band. However, these

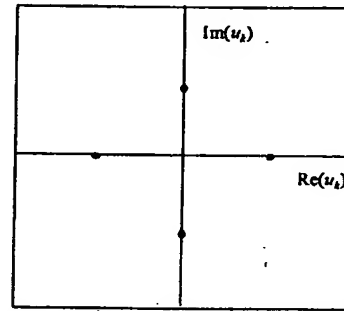
components should be equal to zero. Here we should note that the samples  $r_{kz}$  contain a sequence of zeros, and use the fact that the Fourier transform is the linear operation. That means, if we succeed to restore samples  $p_k$  corrupted by impulse noise, the output from DFT will have the same spectrum as the original signal, i.e. zero frequency components in the guard band. This fact can be used to restore the missing samples  $p_k$ . By solving the system of  $L_{imp}$  complex linear equations

$$\sum_{n=l_b}^{l_b+L_{imp}-1} p_n \cdot \exp\left(-j \frac{2\pi k n}{N}\right) = -R_z(k) \quad (12)$$

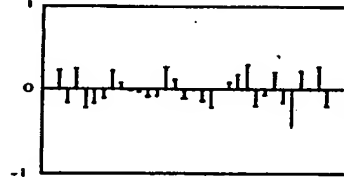
where  $R_z(k)$  are the DFT coefficients corresponding to the frequencies in the guard frequency band, the corrupted samples can be estimated. With the estimates  $p_k$  and the samples  $r_{kz}$ , a signal

$$r_{est\_k} = r_{kz} + p_k \quad (13)$$

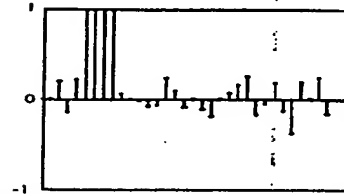
is formed, and the digital information obtained.



(a) frequency domain symbols ( $u_k$ )

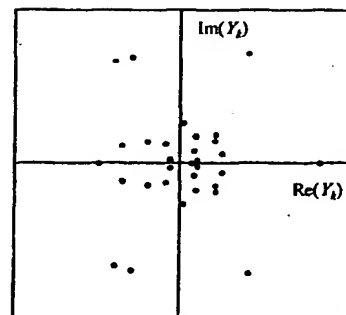


(b) time domain symbol ( $x_k$ )

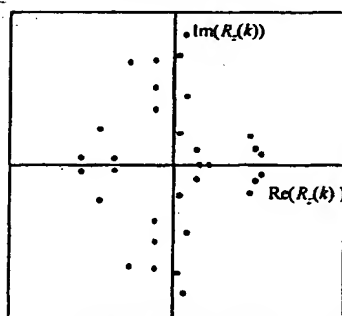


(c) time domain symbol corrupted with impulse ( $y_k$ )

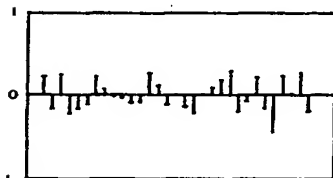
Fig. 2: Steps to cancel the impulse noise



(d) spectrum  $(Y_k)$



(e) spectrum  $R_k(k)$



(f) estimated signal  $r_{est,k}$

Fig. 2 – continued: Steps to cancel the impulse noise

The algorithm was presented with no background noise present, but the simulations have shown that the proposed algorithm has a good performance for moderate signal-to-noise ratios, especially with shorter impulses. The result of the simulation for SNR = 18 dB is shown in Figure 3.

## 5. CONCLUSIONS

A new signal processing algorithm for impulse noise cancellation in the OFDM communication channel is presented. To detect impulse noise and to determine its position within the symbol, a combination of spectrum and power analysis on the received signal is used. The proposed method uses redundancy in the frequency domain to estimate samples corrupted by impulse noise. Estimated samples are combined with the

samples not corrupted by impulse noise, and the estimate of the digital information is extracted from that combination. The simulation results for moderate signal-to-noise-ratio is presented.

The performance of the presented algorithm can be improved if the impulse duration does not reach the maximally allowed length. The performance improvement is achieved by averaging the samples restored with different frequencies in the guard band.

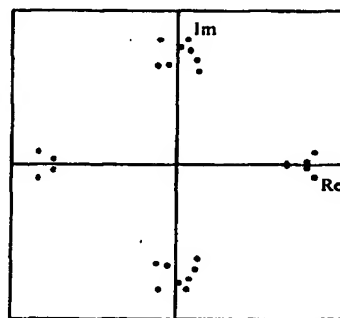


Fig. 3: Spectrum of the signal after impulse noise cancellation for SNR = 18 dB

## 6. ACKNOWLEDGEMENT

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